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The improvement of the production process performance through material flow and storage efficiency increases serial production

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Abstract: In the current era is increasing intention for identifying and mitigating production bottlenecks, particularly in industrial enterprises, by optimizing material and information within the broader context of enterprise logistics. In industrial practice, when applying lean management or any innovation i.e. change in the production process, a common problem is the lack of knowledge of the value stream as a complete system. The efforts of industrial engineers to streamline material flow and warehouse management are closely linked to the reduction of financial resources associated with operations. The paper is focused on improving performance of production process though material flow and storage efficiency increase. The aim of this paper is to describe the implemented analysis of the material and information flow of a selected product and explain the proposed solution to streamline the warehousing system in an industrial enterprise. Desired result was to adjust the size of warehouse at the line, to save production space and to optimize production process in order to maximize the proportion of time in which value is added to the product in the total continuous production time. Different methods (mathematical-statistical calculations, MIFA analysis, MIFD method, guided interview method, observation, GEMBA walk) have been used in the analysis of the current situation. In current turbulent times, when industrial enterprises are pushed to continuously innovate in order to reduce warehousing capacities, it is necessary to continuously improve performance in the context of sustainable business.

1 Introduction

Given the current challenges of the time, it is necessary to look for bottlenecks in the production process and eliminate them to a minimum. Organizations, but preferably industrial enterprises, are trying to save and discover the potential of activities that could bring more added value to the company. If they focus on their internal processes, they primarily follow material, information and financial flow [1,2]. Enterprise logistics is an inclusive term for the complete logistics of the entire enterprise [3]. The term refers to all logistics aspects both internal and beyond the enterprise. The main aspects of enterprise logistics include supply, internal logistics of production, dispatch and distribution of manufactured goods [4]. The purposeful use of logistics that is based on the immediate needs and interests of one enterprise is usually referred to as enterprise logistics [4,5]. In business practice, there are a number of issues that enterprise logistics has to solve. Among the most common issues are [6,7]: transportation (choice of mode of transport, choice of means of transport, etc.), allocation (optimization and placement of products, distribution warehouses, optimization of capacity utilization in production, material handling), assignment (assignment of employees and machines), priorities (in orders, services), optimization of loading operations, optimum utilization of resources. True optimal management of enterprise logistics processes helps to ensure the smooth operation of the entire enterprise [8].

Hence, most of the issues related to enterprise logistics are related to material flow management. It is the material flow, that is the majority part of manufacturing enterprises and without effective problem solving, it is impossible to ensure the optimal transformation process of the enterprise. Material flow is defined as the movement of material in the production process, including storage [9]. In a broad sense, it starts with the unloading of material on the company's territory, leads through warehouses, production and ends with the dispatch of finished products or waste on the company's territory [10]. The material flow includes all types of materials that are needed to carry out the production process, as well as their movement in the process [11]. Logistics systems are networks for the distribution of goods using transformation processes that create material flow through the coordinated movement of goods [12]. Figure 1 shows a graphical representation of material flow in the frame of enterprise logistics.

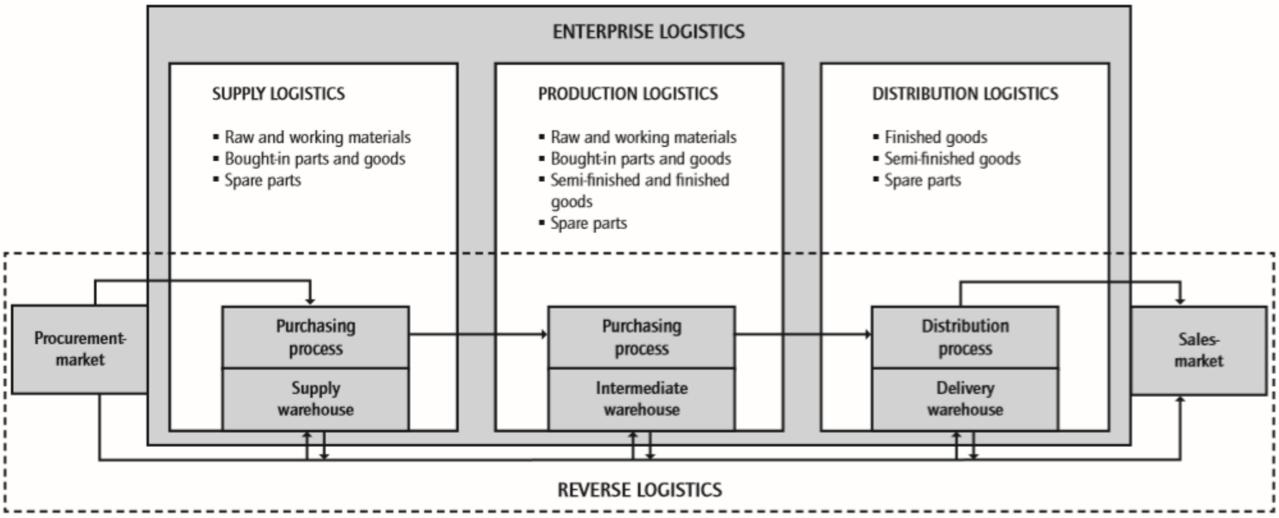

Figure 1 Logistics system according to material flow phases in an industrial enterprise [13]

As can be seen in Figure 1, the material flow of an enterprise is closely related to the supply chains, the internal logistics as well as all production processes of the enterprise [13]. In order to implement material flows, the coordination of personnel, technical resources (machines, vehicles, freight units), inventories, space utilization, information and energy flows must be organized [14]. These include, on the one hand, the processes of transport, handling, storage, packaging and labelling that constitute and support the material flow, on the other hand, order handling and order processing and all related information management and communication flows. Material flow mainly includes [15]:

- actual movement in space - transport, handling,
- storage of finished products in the warehouse of the manufacturing enterprise,
- storage in the warehouse of a trading, supply, sales organization,
- preparation of products for the working shift.

The goal of an efficiently designed material flow is the economical movement of passive elements (materials, raw materials, semi-finished products, products) provided by active elements (transport, handling and storage systems) [9]. A straightforward and simple flow is considered to be the basis of efficiency, which depends on the optimal spatial distribution in the enterprise for both production and warehouse objects [1]. Also important is the low frequency of material flow, which allows the formation of larger, yet volume-integrated handling units that are handled as a single piece when using mechanization means [16]. The main objective is to design better technical and organizational solutions for material flows in production and circulation, not only by mechanizing or optimizing handling operations, but also by optimizing information systems in time and space [8,15]. Closely related to material flow is information and energy flow, which is directly related to the provision of material flow [17]. The industrial practice of the 21st century is directly related to the provision of information flow, which ensures the smooth and running of the material flow along with the running of the entire enterprise [18]. In the case of streamlining material flow, it is necessary to implement enterprise information systems that are based on the principle of collecting data from the entire information flow, which is related to the provision of enterprise logistics [19]. It is the information flow that is directly related to smart enterprise logistics system solutions.

Warehousing is one of the most important parts of the logistics system, which provides storage of products at the point of origin and between the point of origin and the point of consumption [20]. Warehousing allows bridging space and time in the production system. Production inventories ensure the continuity of production, while trade goods inventories ensure the continuous supply of the market. The fundamental role of warehousing is to volume balance and align differently sized material flows within the enterprise [9]. Lean management has now come to the fore mainly in the field of warehousing, the main reason being to minimize the costs associated with warehousing. Trends in lean management will further eliminate warehouse capacity in the future, either due to more efficient use of warehouse space or to reduce warehouse costs [16,21].

Due to the fact that many business entities do not perceive the management of the enterprise as an integrated system, duplication of measures arises, which are often ineffective [22]. Logistics can be considered as an integrated discipline that integrates the management of the three basic flows in an enterprise (material, information and financial) [19]. If industrial enterprises have to succeed in today's turbulently changing business environment, it is necessary to address management in the context of lean management and the application of optimization and racialization methods [18,20].

2 Materials and methods

Value Stream Mapping in Western European countries is strongly influenced by the lean philosophy, which together with the Value Stream Mapping is VSM method has also spread into Slovakia. From Toyota of Japan came the concept of Material and Information Flow Analysis is MIFA and Material and Information Flow Diagram is MIFD, which gradually began to be adopted by other organizations that applied lean manufacturing [23]. Among the first authors dealing with value flow and its analysis are Mike Rother and John Shook, who published the book "Learning to See" in 1999 [7,21]. The MIFA method is a lean manufacturing analytical tool that maps manufacturing, logistics and management processes in a clear and detailed way. The aforementioned insight is implemented in MIFD, which represents the first step of the streamlining process within the described analysis. Based on the customer requirements and the possible production capacities of the manufacturer, the MIFA and subsequently the MIFD can be implemented.

The basic attributes of MIFA are the respect of the principle of conservation of material (matter) so that the system under study is represented by processes, stocks and monitored flows. The system under study is specified by a system boundary defined in terms of a reference space, a reference time frame and one or more reference materials. The reference time frame may be a time period, such as a year, a month, a week, or a specific date, such as an end of the reference period (e.g. end of a year) [24]. The constructed analyzed flow diagrams display the analyzed information by distinguishing between transformation, distribution and storage processes. Material inventory and flow data are also visualized using other types of diagrams, such as Sankey diagrams and system dynamics diagrams, which show some of the attributes analyzed [25].

The aim of the implemented analysis was to identify bottlenecks in the material and information flow of the production of the selected product using lean management methods. The purpose of the implemented analysis was to propose a solution to streamline the warehousing system in the selected company and to increase the efficiency of the production process.

3 Resulting design of efficient material and information flow

The following part of the paper covers the analysis using the MIFA method, as well as the solution resulting from the analysis, which aimed to rationalise the material and information flow. Storage is an integral part of the production system. The basic functions of warehousing include the quantitative and time balancing of differently sized material flows [26]. However, it is perceived negatively in the principle of downsizing and companies should try to reduce warehousing to a minimum if it is not a technological warehouse [2]. Therefore, the authors of the proposal focused on the optimization of storage in the production process. The first warehouse with optimization potential is the warehouse of components, which is located in the first part of the product assembly. The product is pressed in the plant and hung in the hook warehouse at the press shop, from which the logistics operator moves it on a handling trolley (the parts are still hanging on the hooks) to the warehouse at the assembly. Eight parts are hung on one hook. These parts are pressed in three versions, so their supply must be computer-controlled. Currently there is space for two rows of full hooks and one branch for empty hooks in the warehouse. In total, the built-up area in the line can be defined at 2.66 x 8.10 m, which is 21.55 m^2. In the new layout we propose only one branch for parts and one for empty hooks.

3.1 MIFA analysis

The first step in mapping the value in MIFA is the customer analysis. Due to the fact that the stimulus for production are orders from the customer, the MIFA analysis starts as if from the end of the production process. In the analysed industrial enterprise, there are working two shifts, the morning that works from 6:00 am to 2:00 pm and the afternoon shift from 2:00 pm to 10:00 pm. The break time is set at 30 minutes during the working shift. It follows that the net production (working) time is 15 hours (1). The authors of the proposal considered a 40 working week year, and the customer has placed an order for 798 products.

$$Tact\ Time = \frac{production\ time/day\ (daily\ production\ time)}{ordered\ volume/day\ (daily\ ordered\ volumes)} = \frac{54000}{798} = 68\ s. \quad (1)$$

The customer is in close proximity to analysed enterprise, which represents a Just in Time is JIT supplier. The location of customer is approximately 90 km away from the industrial enterprise under analysis, which represents approximately 80 minutes of transport time for the finished products in a truck. The customer sends orders for 62 references (options), i.e. finished products. Currently 3 basic versions of the final product are produced. All three products can be customised and supplemented with different variants according to individual requirements, resulting in the aforementioned

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62 options, a mix of which the industrial enterprise orders from its supplier. Fixed orders arrive every Monday morning, with orders being issued Tuesday to Monday for the whole week for each single truck. Forecast orders are available to the logistics plant staff for one month in advance, but these can still be changed by the customer as required. In the analysed enterprise, orders are processed by the Customer Contact and the Master Scheduler. The orders information is used in the Plan Directeur de Production is PDP meeting, where production for the following week is planned. The PDP meeting is held every Thursday and is attended by the Plant Director, the PC&L Manager, the Master Scheduler, all UAP managers (assembly, press shop, paint Shop), the HR Manager, the FES Specialist and the maintenance Coordinator. In the meeting, weekly production, finished goods warehouses, required number of production staff, production time and maintenance are planned together on a daily basis. The meeting where the transportation plan is created once a month (every third Thursday) is called PIC (plan industrial et commercial) and is attended by the same persons as the PDP meetings. The transport plan (estimated for 6 months) is then updated on the basis of the weekly PDP and information from the material planner, i.e. the logistician, who plans the supplier orders on the basis of the PDP (planned production). From the transportation plan, a board-truck arrival plan is created, which is placed in the truck receiving area in the office of the administrators. Pick up sheets are also generated and sent with the orders to the suppliers, which is one of the tasks of the material planners.

The second step is supplier analysis. This information flow takes us to the other end of the production chain, to the suppliers. We can divide the purchased parts in the company into 3 basic groups:

- Bought Out Parts is BOP - parts that are purchased by the industrial enterprise and enter the product in the production process,
- PLS - parts that the industrial enterprise buys and sends to customers according to orders (no technological process takes place),
- Raw Material is RM - raw materials, which is considered to be the granulate used for pressing and the inks used for painting the parts.

The granulate used for moulding plastic parts for NSF IP is purchased by the company from 4 suppliers. The material planner sends fixed orders and forecasts to these four suppliers, depending on the agreement and contract, how often and for how long. Regarding the transport of material to the industrial plant we attach a summary table (Table 1).

Receiving an order from a customer starts the information flow in the enterprise. When the truck arrives at the plant and is let in from the gatehouse by the administrator to the unloading position, the material (granulate) is unloaded into the annex, where it has its storage place. It takes the A2 operator approximately 60 minutes to unload and store the material (granulate). He uses a forklift to unload, taking one octabin (an octagonal transport box designed for bulk material, that can be made to customer requirements) of granulate per turn on the skids. He places the octabins in the designated places in the annexe next to the tunnel with unloading positions. Each of the materials (granulates) has a storage capacity of 4 rows of 7 octabins (approximately 30 tons of material). For each of the materials (granulates), there is a storage capacity of 4 rows of 7 octabins (approximately 30 tonnes of material).

Table 1 Summary of granulate suppliers (Based on internal company sources, 2020)

Supplier	Distance	Transport time	Delivery frequency	Truck capacity
Supplier 1	958 km	10 hours	1/4 weeks	22 octabins
Supplier 2	1330 km	13.5 hours	1/5 days	22 octabins
Supplier 3	1100 km	11 hours	1/4 days	22 octabins
Supplier 4	35 km	0.6 hours	1/2 weeks	22 octabins

The third step is the analysis of the finished products, which the operator at the second final control places in a container next to the line. The container fits 6 finished products that are not mixed. There are products of one type in one container. That is the reason why there are 3 containers, so that in case of a long polishing or other problem, other final products can be finalised. The logistics operator Picker A2 picks up the parts every 10 minutes or so, and after printing the delivery form and scanning the galley, takes them to one of the three TPAs. The TPA (Truck Preperation Area) is place, where the finished products are stored prior to loading in the composition and number that will be loaded onto the customer's truck. Two products are always picked and serve as safety stock at the same time and one is always in the process of being prepared. The capacity of one TPA is 34 containers, that represents 204 parts, and this is also the quantity transported in one truck. The trucks go to the customer 4 times a day. The arrival times at the industrial enterprise are: 08:30, 10:00, 13:00 and 16:00. It takes 60 minutes to unload the empty packages, load the full ones and process the delivery forms.

The fourth step of the MIFA method is creation of a graph, which is also considered as the output of MIFA (Material and Information flow analysis) or the diagram from the analysis which is a lead time diagram, i.e. a time diagram of the entire production process together with the transportation of material and storage. The shape of this diagram can be seen in Figure 2, where it is in a very reduced form extracted from the MIFD.

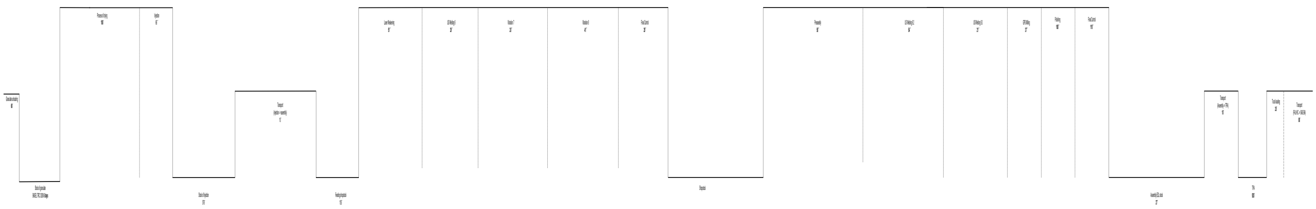

Figure 2 Shape of lead time diagram from MIFD (Own elaboration, 2020)

The whole process is divided into three levels:

- production time - when the actual value is added to the product (the highest part of the diagram) (2),
- transport time - when the material or product is moved (lower part of the diagram) (3),
- storage time - when the material or product is stored in the plant (middle part of the diagram) (4).

$$Production\ time\ [\%] = \frac{Production\ process\ time}{Total\ time} = \frac{3.2}{174.4} = 1.83\% \quad (2)$$

$$Transport\ time\ [\%] = \frac{Transport\ time}{Total\ time} = \frac{1.8}{174.4} = 1.00\% \quad (3)$$

$$Storage\ time\ [\%] = \frac{Storage\ time}{Total\ time} = \frac{169.4}{174.4} = 97.16\% \quad (4)$$

We chose the product TC for analysis because it enters the production process first and thus has the longest production time. The total continuous production time is 174.4 hours from the arrival of raw material to the loading of the finished part into the truck. This time is divided into 3 categories (Table 2). Where the contribution of each activity to the total time is also calculated. The actual value added to the product is only 1.83% of the total continuous production time. The largest part of this time is warehousing, which accounts for more than 96%.

Table 2 Total continuous IP production time divided into 3 categories from MIFD (Own elaboration, 2020)

Name/ Values	Seconds	Minutes	Hours	Percent [%]
Production process	11 517	192	3.2	1.83
Transport	6 300	105	1.8	1.00
Storage	**609 900**	**10 165**	**169.4**	**97.16**
Total	627 717	10 461.95	174.4	100.00

The performed MIFA analysis shows that storage is the bottleneck in the product manufacturing process. From the carried-out analysis conclusions were developed, presented in the following section.

3.2 Conclusions from the analysis

Within the framework of the analysis, the material and information flow of the selected product was mapped in detail. The lean manufacturing tool MIFA was used in the implementation of the analysis and created a MIFD value stream map. In Figure 3, we can see the visualization of material and information flow in the selected industrial enterprise for the selected product.

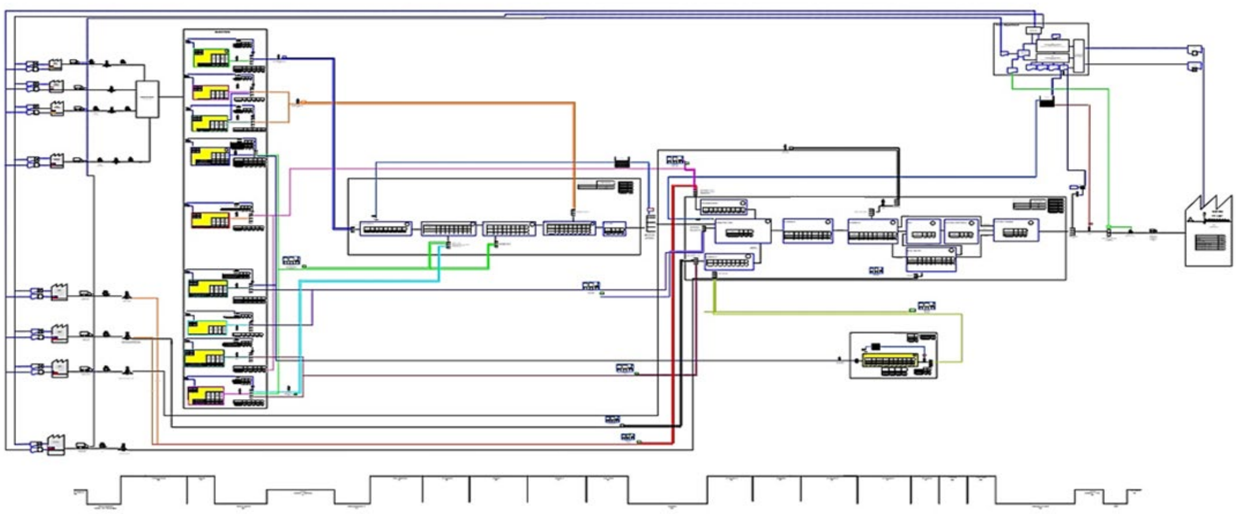

Figure 3 Material and Information Flow Diagram for the selected product (own elaboration, 2020)

The material and information flow map comprehensively maps the production process flow from suppliers to the end customer. Production process flow does not only mean the flow of material, but also the flow of information that precedes the flow of material. The main objective of the MIFA method is to reveal production flow potentials and change opportunities in the whole process. The result indicator is the proportion of time in which value is added to the product in the total continuous production time. The objective is to maximize that proportion and to do so to some extent by reducing material storage and transportation time. As mentioned above storage in the production process came out as risky and hence there was scope for designing a comprehensive measure to streamline the production process in the selected enterprise in Slovakia.

3.3 Calculation of the necessary storage capacity

With a production volume of 798 products and a net production time of 20.25 hours, the hourly production is 40 units of products. The infeed warehouse at the line is stocked by an operator who has a 10 minute circuit. This means that every 10 minutes he brings 8 pieces of products on the hook. According to the company's internal rules, the assembly warehouse should have a capacity of 2x the cycle time of the supply train or the operator (adequate to production) plus one extra pack. This means that if the parts were supplied by a milkrun (30 minute cycle time) the warehouse would have to have capacity for an hour's production. In the above case, the warehouse would only need to have capacity for 20 minutes of production plus one hook. This equates to 3 hooks and 24 pieces. Current capacity is 2 rows of 6 hooks, totally 12 hooks (96 parts). The proposed capacity is 1 row with 6 hooks, which means 48 parts in stock. Thus the requirement of 24 pieces remains unfulfilled.

Another warehouse that is, based on the analysis, unnecessarily large is the Defroster Duct is DD warehouse. Similar to the Top Cover is TC components warehouse, the part is pressed in-house and transported internally on hooks. There are more similarities in the handling of this component, such as the same logistics operator handling the components from the press shop warehouse to the assembly warehouse, or the same capacity on a single hook. The difference between handling of these components is that in the line, this warehouse is located next to the TC warehouse and occupies an area of 2.09x8.1m = 16.93 m^2. There are also two rows for full hooks and one return branch.

As a further change related to the reduction of the above-mentioned warehouses, we propose to mirror turn the line and thus bring the warehouses for TC and DD closer to the press shop warehouse. The distance between warehouse will be reduced by approx. 15 m for 8 components (1 hook). This means that with a daily capacity of 798 products, the indicated distance will be traversed 200 times (2 parts). In one shift, the operator thus walks approximately 1 km less (time saving of approx. 50 minutes). From the opposite side, the parts will be supplied by a train, which can travel on the other side of the line. With the explained solutions, the machines in the line will be brought closer together and the line layout will be made more efficient as can is visualized in the Figure 4.

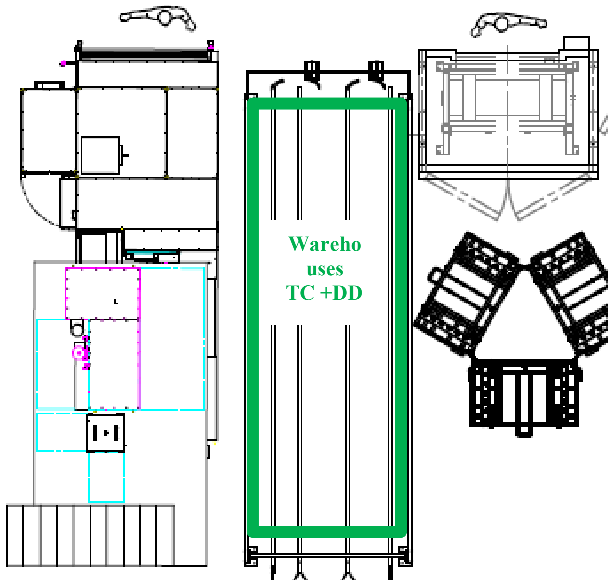

Figure 4 Proposed layout of workplace Assembly 1 with reduced warehouses (Own elaboration, 2020)

In the proposed layout we consider only one full and one empty branch. The capacity calculation would be identical to that for the TC part. Required capacity are 3 hooks (24 parts). Proposed 1 branch have 6 hooks (48 parts). The main idea remains that we are proposing to reduce the storage capacity of 96 parts to 48 parts. The proposed layout will require a change in the stocking of the line in the exact order in which products are produced. The TC part has 3 versions and the DD part has 2 versions. The product is produced in batches, and when a version change is made, the mould must be changed on the welding machines (approximately 15 minutes). According to the Kanban system, the assembly leader 1 has the information to change the production to a different version, and he must inform the logistics operator in time to already supply the necessary parts. The proposal is to introduce the use of hanging boards with the name of the reference, which if the GAP leader hangs in the warehouse, the logistics operator will know that he has to stock other parts. Consequently, the proposal is to retrain the operators working in this position to stock the warehouses according to the above instruction. The intention is not to take parts off the line back to the press shop warehouse when the production reference changes, but to bring only the exact number of parts that will be produced in a given batch to the line.

3.4 Summarization of warehouse optimisation

In an industrial company, the need arose to ensure that the necessary space was found for a new project in the production hall. This means the possibility of relocating machines, changing their place in the line, or adjusting the size of warehouses in order to optimize the production process or save production space. The reduction of the warehouses at the line (TC and DD parts) means a saving of 18.23 m^2 as can be seen in Table 3.

Table 3 Space saving for Assembly Line 1 (Own elaboration, 2020)

Warehouse of component	Current status	Proposed status	Savings
TC	2.66 x 8.1m = 21.55 m^2	1.4 x 8.1m = 11.34 m^2	10.21 m^2
DD	2.09 x 8.1m = 16.93 m^2	1.1 x 8.1m = 8.91 m^2	8.02 m^2
Total	4.75 x 8.1m = 38.48 m^2	2.5 x 8.1m = 20.25 m^2	18.23 m^2

An even greater benefit of the design measure than the savings in storage space is the closer proximity of the machines in the line, as the warehouses are located between the 2 machines. This will reduce the walking time of the operators in each cycle. The estimated saving is 7 seconds per part, a significant time saving for the capacity of the production. Especially in a situation where the line operates in 2 models, where are needed 2 or 3 operators. The third operator is a GAP leader who should not spend most of the working time in the line. The intention of the management is to work with only 2 operators, so any speeding up of the production process is important.

Another significant area saving is the reduction of intermediate storage. In this case, we are talking about an area of 44.1 m^2, calculated as follows: original warehouse area: 7 x14.5 = 101.5 m^2. Proposed warehouse area: 7x8.2 = 57,4 m^2. Area saving: 101.5 – 57.4 = 44.1 m^2. The saved area will be divided on both sides of the warehouse. On one side (where the TC and DD warehouses will be) there will be an area of 4 x 7 = 28 m^2 and on the other side the remaining 2.3 x 7 = 16.1 m^2. On the first area is proposed to create a GAP for the production line. GAP means a meeting area for the TOP 5 for each shift, lockers for employees and boards to keep track of different products related to the production lines. On the other side of the warehouse, there will be space for a rework table and a new welding machine, or other necessary measuring jigs. Compared to the original layout, the transport route is proposed to be shortened and reduced by about 15 metres to 8 parts (1 hook). This means that the operator walks 1 km less per shift when stocking these parts, leaving time for stocking other parts.

4 Conclusion

At the industrial plant where the analysis was carried out, it was decided that the NSF line would be moved to provide the necessary space in the production hall for the new project. By applying the chosen methods and implementing the proposed changes, it was possible not only to shorten and simplify the material flow, but also to optimize the production process and save production area. The reduction of the warehouses at the line (TC and DD parts) means a saving of 18.23 m2. An even greater benefit was the saving of the warehouse area thus shortening the walking time of the operators in each cycle. The dog time to simulate the process is not known, but the estimate is 7 seconds per part, a significant time saving at the size of the production. Especially in a situation where the line operates in 2 models - 2 or 3 operators. The goal was to run the procees with only two operators, which was achieved by the optimization implemented. Another benefit was that, compared to the original proposal, the transport route is proposed to be shortened and by about 15 meters to 8 parts (1 hook). This means that the operator will travel 1 km less per shift when supplying these parts and will have time to supply other parts.

Within the presentation of the carried-out analysis, the product production process was described in terms of material and information flow, which provided an opportunity to develop a proposal for providing and managing change due to the need to create space for a new project. As part of the analysis, a current material flow value map was created, which allows managers, planners, project engineers and other specialists in the company to not only see the value in the material flow, but also to distinguish it from waste and eventually get rid of it [14]. The map allows to identify each process located in the value stream, to clearly define it in the confusing and opaque structure of an industrial enterprise, and to build the value stream based on the principle of lean [17]. It is up to the lead employees of the enterprise how often they use the map and with what frequency to update the data, but at least when changes are made to the product's production process, it will provide an important information base. Based on the analyses performed and the design implemented, it was possible to streamline the production process in the analysed industrial enterprise. The mentioned proposal contributed to the improvement of not only the company logistics, but also ergonomics, production effectiveness, or overall performance of the company.

The MIFA method as well as the above rationalisation process can be used repeatedly or in combination with the use of Just in Time (JIT). It is important to sub-detailed monitor and analyse all the factors analysed. If the inputs are not sufficiently monitored there is a risk of bias in the results after the application of MIFA analysis.

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Review process

Single-blind peer review process.